Test Summary

On 03/31/15, d-HYBRID contracted Sensors, Inc. to conduct in-use testing of a stock class 8 truck, as described below, equipped with their DD1000 Mixed-Fuel System, which combines compressed natural gas with standard diesel fuel at various rates depending on the operation mode. The purpose of the test was to demonstrate that gaseous and PM emissions in mixed-fuel mode are the same or lower than the stock configuration for this engine family.

Emissions were measured in both a baseline configuration with standard diesel fuel, and mixed-fuel configuration. Additional after-treatment was used during mixed-fuel testing. Two baseline runs were performed, consisting of city and highway driving. The identical route was then performed in mixed-fuel mode and compared to the baseline averages. Gaseous and particulate matter emissions were less than, or equal to the baseline runs using results rounded to the same significant figures as the EPA standard for this vehicle. While non-methane hydrocarbons increased slightly, the difference was within the measurement uncertainty of the two large hydrocarbon concentrations.

Test Information

1.

Test Dates	03/31/15 thru 04/03/15
Location	Wesley Chapel/Brooksville, Florida
Vehicle Description	March, 2003 Detroit Diesel 12.7L (S60) ESN: 06R0726357, in a 2003 Freightliner SN: 1FUJA60G74LM19876 with over 1,041917 miles. Weight of the tractor plus the weighted trailer, test equipment and passengers was 72,560 lbs.
Engine Families seeking approval	a. 2DDXH12.7EGL, 2DDXH14.0ELL, 3DDXH12.7EGY, 3DDXH14.0ELY, 4DDXH12.7EGY, 4DDXH14.0ELY, 5DDXH12.7EGY, 5DDXH14.0ELY, 6DDXH12.7EGY, 6DDXH14.0ELY, 7DDXH12.8DJA, 7DDXH14.0ELY, 8DDXH12.8DJA, 8DDXH12.8DJC, 8DDXH14.0ELY, 8DDXH14.0ELC, 8DDXH12.8TER, 8DDXH14.8EEY, 8DDXH14.8EEC, 9DDXH12.8DJA, 9DDXH12.8FED, 9DDXH12.8TER, 9DDXH14.0ELY, 9DDXH14.8EEY, 9DDXH12.8DJD, 9DDXH12.8FEY, 9DDXH14.0ELD, 9DDXH14.8EED with ECM, TC, CAC, EGR, and DOC and per EPA Engine Models and Parts information Dockets)

Participants

Name	Affiliation / Title
Carl Ensfield	Sensors, Inc. , Applications Engineering Manager
Chris Darby	Sensors, Inc. , Senior Applications Engineer
Vio Philip	Sensors, Inc. , Senior Field Engineer
Thomas Sewell	Sensors, Inc. , Factory Technician
Morgan Mackelprang	d-HYBRID, Project Manager
Stephen Scott	d-HYBRID, Software Engineer
Denton Sullivan	d-HYBRID, Driver

Test Equipment

Prior to testing, the SEMTECH-DS unit and Methane FID, the SEMTECH Micro-proportional diluter, and the Exhaust Flow Meter were calibrated and verified to meet linearity requirements of CFR 40 Part 1065 Subpart D. In addition, the SEMTECH-DS unit underwent standard preventative maintenance procedures including leak checks and filter changes. The Gravimetric Filter System was also tested for leaks. Included below is a list of major components followed by consumable calibration gases and fuel gases:

SN	Component
A06-SDS01	SEMTECH-DS Gaseous Analyzer
L04-SN01	SEMTECH Methane FID
G09-SM02	SEMTECH Micro-proportional Sampler and Exhaust Flow Meter
H09-FS03	SEMTECH Gravimetric Filter System
39411	Exhaust Flow Tube (5”)
G5030013	Vaisala Weather Probe
1A4155786	Garmin GPS Model# 16-HVS

Calibration Gases Used

Cylinder	SN	Lot	Expiration
15.1% CO_2, 1220 ppm CO, 1003 ppm NO, 252 ppm C3, bal N_2	FF17007	0126DJ15	01/26/17
9330 ppm Methane, bal Air	FF49266	0210RF14	02/10/16
255 ppm NO_2, bal Air	EA0005427	1030HE13	10/13/15

FID fuel: 40PCT H2 / 60PCT He2	BC1267706 CK0945489 CK0986087 CK1035330 CK1057188 EA0009164	1108RX13 1219SB13 1219SB13 1219SB13 1219SA13 0112GB15	11/08/15 12/19/19 12/19/15 12/19/15 12/19/15 01/12/17

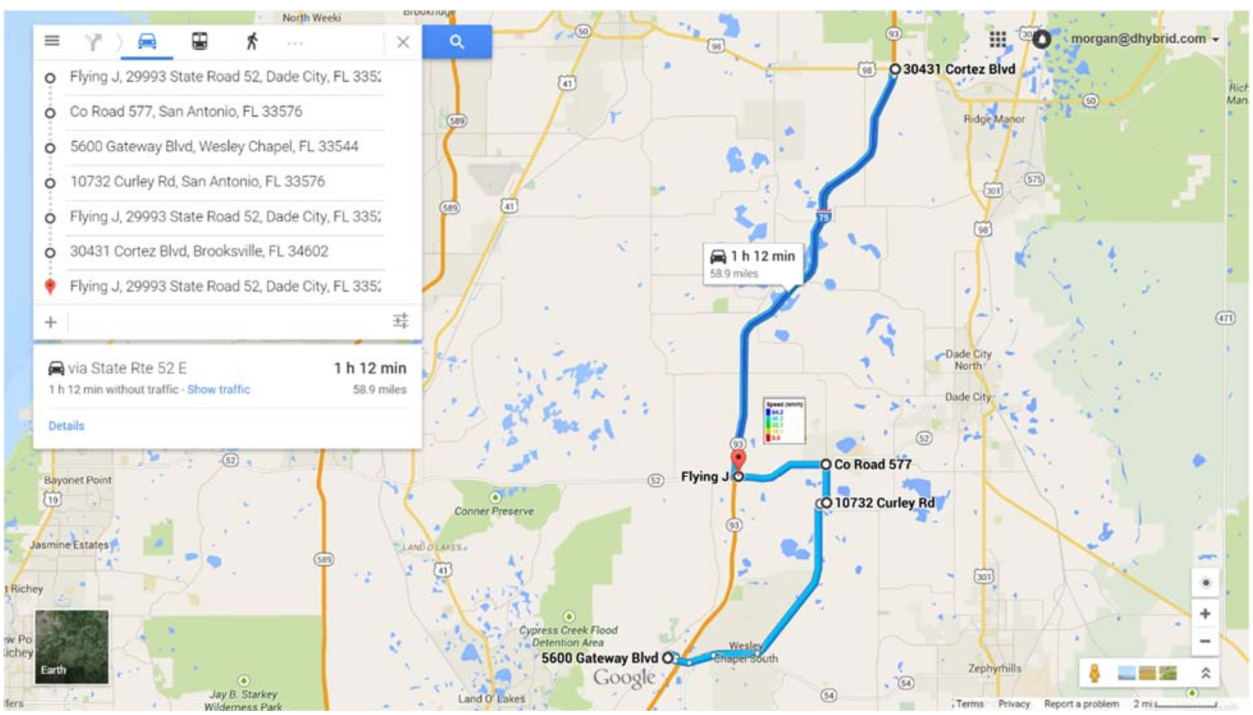
Test Procedure

The SEMTECH-DS was calibrated using NIST traceable gases each day before and after the test routes were performed. Both the THC FID and the Methane FID were calibrated using the same span cylinder of Methane. Zero calibrations were performed using ambient air as allowed under EPA HDIU testing rules.

In addition, routine assessments were performed to ensure satisfactory performance throughout the test process. These included:

- examining multiple system pressures and temperatures for normal operation
- performing leak tests
- checking for zero drift and performing zero calibrations as needed
- verifying proportionality of the PM dilution system

Emissions were measured over the test route shown on the following map. The test route consisted of a round trip from Wesly Chapel Florida to Brooksville Florida, as shown. The route consists of a total of 58.9 miles, with a 60/40 split of highway and urban driving. Estimated drive time did not include routine traffic and highway construction.



For each test cycle, gaseous mass emissions were measured on a continual basis and integrated. PM mass was collected on a single 47 mm Teflo filter for each test cycle, which was pre-weighed at University of California Riverside using standard laboratory procedures. After testing was complete, the filters were sent back to UC Riverside for post-test conditioning and weighing. PM mass at the tailpipe was computed based on the measured PM sample rate and the dilution ratio from the proportional diluter.

The engine work over the test cycle was determined from the baseline runs using the vehicle's ECM interface with SAE J1939 protocol. To compute brake torque, the SEMTECH-DS post-processing software performs the following calculations using three ECM parameters:

Total Torque = *Percent_Torque x Reference_Torque*
Frictional Torque = *Percent_Frictional Torque x Reference_Torque*
Brake Torque (net torque) = Total Torque - Frictional Torque

Because of the fuel substitution, the ECM cannot compute the true torque during mixed-fuel mode; so we instead use the average work from the diesel baseline cases to calculate brake-specific emissions during these cycles. We believe this is a valid estimate, since the vehicle was operated on the same route at the same speed and with the same load.

Fuel properties are used in the dry-wet correction of the measured gas concentrations. During the baseline cycles, standard no. 2 diesel properties were used. During the mixed-fuel runs, it was estimated that a 50% mix of CNG and diesel was typical, so fuel properties were based on this mixture.

Molar Ratios of Fuels

Fuel	C	H	O
No. 2 Diesel	1	1.80	0
Mixed-fuel	1	2.90	0

For NMHC calculations, the Methane mass emissions were integrated separately and then subtracted from the THC integrated mass. This is because the Methane FID is considerably slower in time response than the THC FID due to the non-methane cutter, so NMHC cannot be computed on a second-by-second basis. When computing the second-by-second Methane mass results, the Exhaust Flowrate and Methane concentration values were dispersed via 30-second averaging in order to achieve similar response rates for these two signals before they were multiplied in the mass calculations. A detailed example is provided in the Results section.

Test Records

Date	Test	File Name	Test Operator
03/31/15	Diesel1	DHY_Diesel1.csv	C. Darby
03/31/15	Diesel2	DHY_Diesel2.csv	C. Darby
03/31/15	Diesel3	DHY_Diesel3.csv	C. Darby
04/02/15	MFuel1	DHY_MFuel1.csv	C. Darby
04/02/15	MFuel2	DHY_Mfuel2.csv	C. Darby

Results

The following tables summarize the emissions results of the two test routes. Averaged results (in bold font) were rounded to the same number of significant digits as the applicable emissions standards for the test vehicle. This is a routine practice for HDIU testing.

Gaseous and particulate matter emissions for mixed-fuel were less than, or equal to the baseline runs using results rounded to the same significant figures as the EPA standard for this vehicle. While non-methane hydrocarbon emissions increased slightly, the difference was within the measurement uncertainty of the two large hydrocarbon concentrations.

Test Results

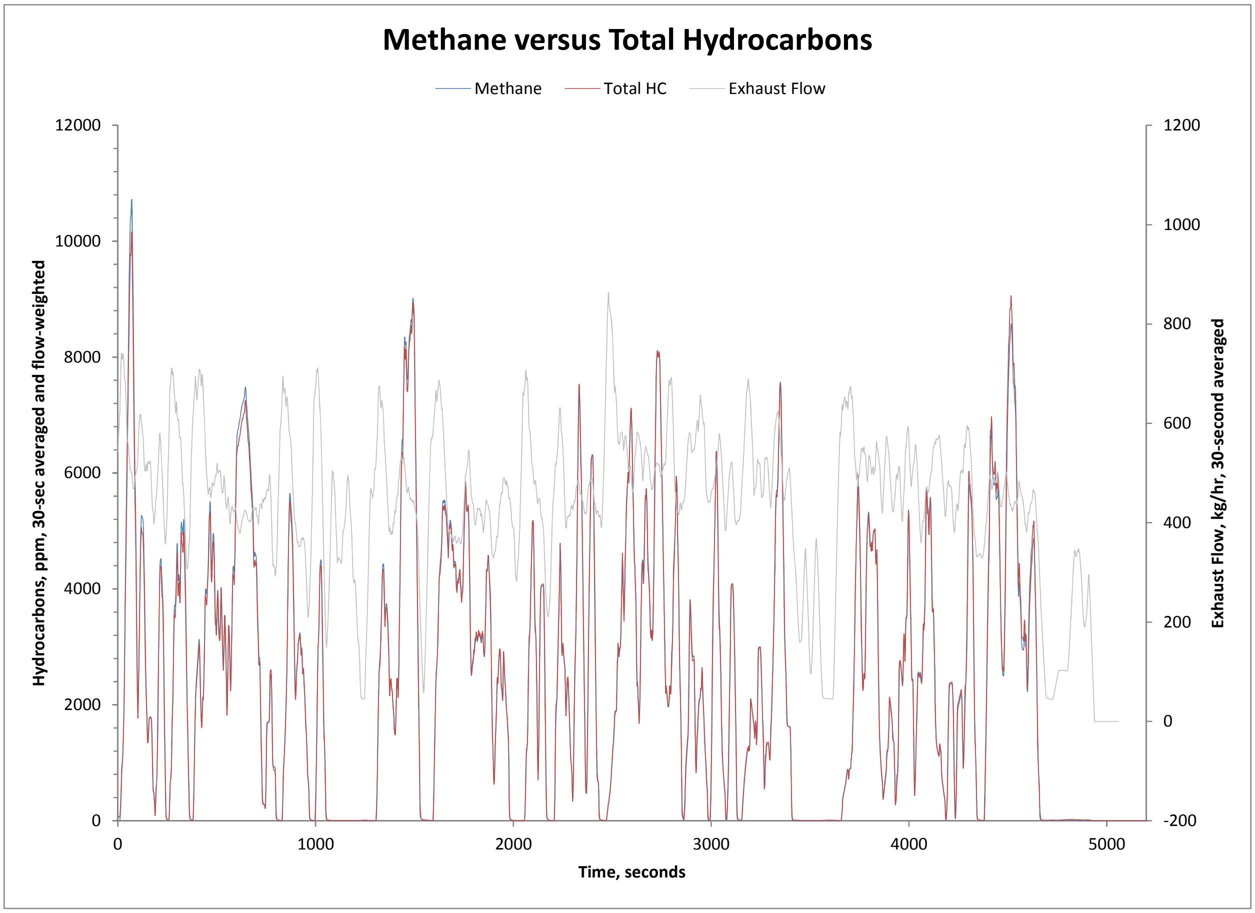
	Test	Duration	Temp	RH	Kh	Emissions, g/bhp-hr				
date		Sec	deg C	%		CO_2	CO	NOx	NMHC	PM
03/31/15	Diesel1	5072	25.66	57.20	1.02	507.0	1.14	2.56	0.04	0.12
03/31/15	Diesel2	5116	24.01	61.94	1.02	504.0	0.87	2.70	0.03	0.10
03/31/15	Diesel3	5056	20.88	76.08	1.02	515.0	0.98	2.88	0.03	0.10
Baseline Average	**Diesel**	**5081**	**23.52**	**65.07**	**1.02**	**508.5**	**1.0**	**2.71**	**0.03**	**0.11**
04/01/15	MFuel1	4937	17.01	93.32	1.01	425.6	1.00	2.54	0.00	0.09
04/03/15	MFuel2	4967	20.73	76.51	1.02	434.5	0.88	2.60	0.09	0.09
Mixed-fuel Average	**Mixed-fuel**	**4952**	**18.87**	**84.86**	**1.01**	**430.1**	**0.9**	**2.57**	**0.04**	**0.09**

Several other tests offered similar gaseous results to the above mixed-fuel values, including tests CNG09 and CNG11. (These two tests offered a favorable gaseous and gravimetric filter delta pressure; however, formal actual particulate matter results were not available.) Particulate matter results were otherwise repeatable. Tests CNG12 and CNG13 were deemed invalid given the excessive traffic delays resulting from road construction.

Non-methane calculation:

Non-methane hydrocarbon determination was performed using two flame ionization detectors (FIDs): a total hydrocarbon (THC) FID and a Methane FID which contains a non-methane cutter to remove other hydrocarbon species. Because the Methane FID has a significantly slower response rate than the THC FID (due to the non-methane cutter), second-by-second NMHC determination was not possible. Instead, a flow-weighted mean concentration of Methane and THC were calculated based on thirty-second moving averages of exhaust flowrate and FID measurements. By using thirty- second moving averages, results were no longer susceptible to larger variations due to time alignment. There were significant spikes of Methane during mixed-fuel runs, resulting in high levels of hydrocarbon emissions. This means we are subtracting two very large values to obtain the NMHC results.

The following chart shows an example of the THC and Methane FIDs along with exhaust flow rate for test CNG08, the first of several optimized mixed-fuel tests, all with thirty-second moving averages. One can observe the similar time response of the two FIDs in this context. This also shows how subtracting these two large and very similar signals can result in NMHC values that are within the measurement uncertainty. Typically for diesel emissions, Methane fractions are a very small fraction of the total (as determined on the baseline tests), so the relative error in NMHC determination is also small.



Conclusions

The test objectives were met; results show that when the vehicle was operated with d-HYBRID's Model DD1000 mixed-fuel system, that both gaseous and particulate matter emissions were the same or lower than the diesel-only baseline configuration.

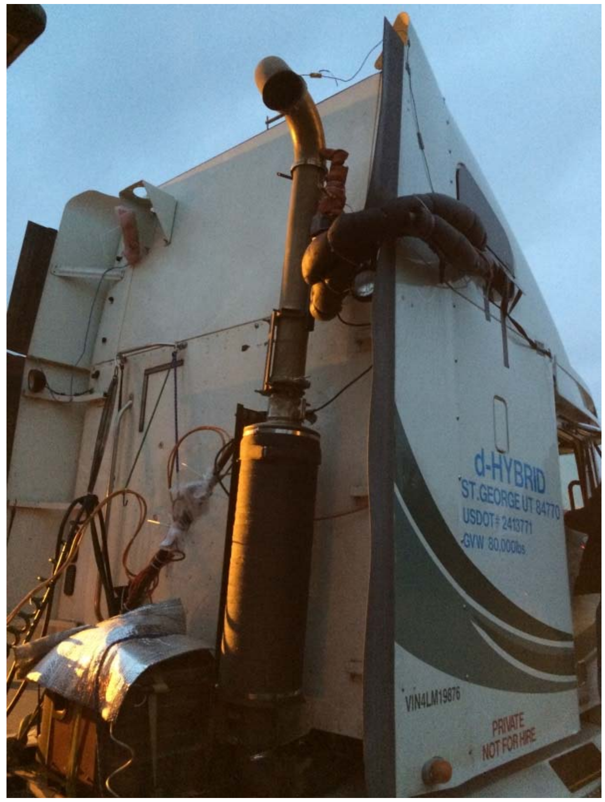
More detailed results and second-by-second data files are also available for review.

Fuel Information		Conversion	Original Vehicle Information					Conversion Vehicle Information		
Conversion Fuel	**Original Fuel**	**Manufacturer**	**Model Year**	**OEM**	**OEM Test Group**	**OEM Evap Families**	**Eng Disp**	**Conversion Evap Family**	**Conversion Test Group**	**Conversion Models Covered**
Diesel or Diesel/CNG or Diesel/LNG	Diesel	d-Hybrid	2002 to 2009	Detroit Diesel	2DDXH12.7EGL, 2DDXH14.0ELL, 3DDXH12.7EGY, 3DDXH14.0ELY, 4DDXH12.7EGY, 4DDXH14.0ELY, 5DDXH12.7EGY, 5DDXH14.0ELY, 6DDXH12.7EGY, 6DDXH14.0ELY, 7DDXH14.0ELY, 7DDXH12.8DJA, 7DDXH14.0ELY, 8DDXH12.8DJA, 8DDXH12.8DJC, 8DDXH14.0ELY, 8DDXH14.0ELC, 8DDXH12.8TER, 8DDXH14.8EEY, 8DDXH14.8EEC, 9DDXH12.8DJA, 9DDXH12.8FED, 9DDXH12.8TER, 9DDXH14.0ELY, 9DDXH14.8EEY, 9DDXH12.8DJD, 9DDXH12.8FEY, 9DDXH14.0ELD, 9DDXH14.8EED		12.7, 14, 12.8		CDHYH12.7EGY	SERIES 60

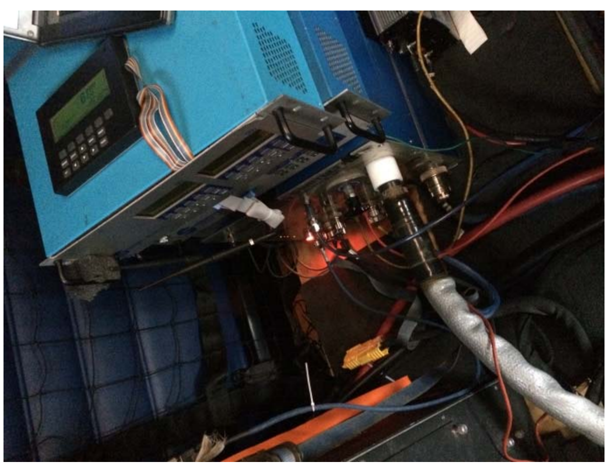
Pictures

Test Vehicle: Freightliner with DDC Engine

SEMTECH Exhaust Flow Meter
with Gaseous and Particulate Matter Sampling



SEMTECH DS and Methane Analyzers



SEMTECH MPS and Gravimetric Filter